Learning Objectives:
- Explain the rationale, indications, and complications for high frequency jet ventilation (HFJV)
- Describe the equipment used in HFJV.
- Explain patient management techniques associated with HFJV
- Apply jet ventilation management techniques in patient scenarios.

High-frequency ventilation types
- High-frequency positive pressure ventilation - conventional ventilation with high frequencies
- High-frequency flow interruption
  - early form of HFV
  - interruption of gas flow from a high pressure source at a high rate

High-frequency ventilation types
- High-frequency percussive ventilation (HFPV)
  - high-frequency pulsations with conventional breaths
  - volumetric diffusive ventilation - Bird VDR 4™ applied to:
    - inhalation injuries - burn centers
    - ventilation during airway surgery
    - neonatal ventilation

High-frequency ventilation types
- High-frequency oscillatory ventilation (HFOV)
  - high-frequency ventilation with tidal volume less than dead space
  - first developed by Emerson - 1950s
  - most common HFV technique for pediatric patients
  - approved, available and used for adults

Click to see Bird VDR4™
http://www.percussionaire.com/VDR4page.asp

Click to see SensorMedics 3100a oscillator
http://www.generalbiomedical.com/Catalog_Photos_LARGE/3100Large.jpg

High Frequency Jet Ventilation
Arthur Jones EdD, RRT
http://rc-edconsultant.com/
High-frequency ventilation types

- High frequency jet ventilation (HFJV)
  - high frequency ventilation with delivery of a tidal volume (1-3 mL/kg) at a high flow (jet)
  - originally used for short-term ventilation during airway surgery (1970s) because of capability to ventilate in face of leaks

Rationale, Principles, Indications & Complications

Rationale

- Small tidal volume minimizes ventilator-induced lung injury and permits greater PEEP - lung protective ventilation strategy.
- Short inspiratory time and small TV minimize flow through leaks.

Mechanism for gas transport

- Bulk convection - jet of gas moves through the center of airways through dead space gas, delivering fresh gas to distal airways, with passive exhalation around the jet stream.

- Pendelluft - collateral exchange between distal units with varying compliance at:
  - airway bifurcations
  - pores of Kohn
  - canals of Lambert
- Simple molecular diffusion

Mechanism for gas transport

- Resonant frequency - lungs have innate resonant frequency.
- Ventilation is augmented because less pressure is required to ventilate lungs at their resonant frequency:
  - 4 - 8 Hz (adults)
  - 10-12 Hz (small neonates)
## Additional effects
- Vibrations and expiratory flow along airway lumen mobilize secretions
- Short inspiratory time minimizes peak alveolar pressure - less pressure is transmitted to alveoli
- Small tidal volume minimizes lung motion during ventilation

## Indications - neonatal/pediatric
- Ineffectiveness of other ventilation methods and BEFORE ventilator-induced lung injury occurs
- Evolving chronic neonatal lung disease (bronchopulmonary dysplasia)

## Indications - neonatal/pedicatric
- Failure of other ventilation methods and BEFORE ventilator-induced lung injury occurs
- Evolving chronic neonatal lung disease (bronchopulmonary dysplasia)
- Congenital diaphragmatic hernia
- Meconium aspiration
- Ventilation during transport, with or without inhaled nitric oxide

## Indications - all patients
- Pulmonary air leaks; e.g., bronchopulmonary fistula
- Difficult airway management
  - ventilation during intubation
  - ventilation during tracheostomy
  - ventilation during bronchoscopy

## Indications - all patients
- Pulmonary air leaks; e.g., bronchopulmonary fistula
- Difficult airway management
  - ventilation during intubation
  - ventilation during tracheostomy
  - ventilation during bronchoscopy
- Elimination of lung motion during chest surgical procedures
- Ventilation during airway surgery
- Ventilation following pneumonectomy
Contraindication

- Effectiveness of conventional ventilation methods.

Complications

- Intracranial hemorrhage
- Periventricular leukomalacia - ischemic white matter injury
- Hypotension
- Air trapping - inadvertent PEEP
- Pneumo/thorax/mediastinum
- Mucosal desiccation - inadequate humidification

Evidence on effectiveness

- Meta-analyses of RCTs on HFJV for premature infants conclude that there is inadequate evidence - not enough trials.
- HFJV is another tool that requires judicious application on a case-by-case basis.

Jet Ventilators

Jet ventilation techniques

- Normal frequency jet ventilation
- High frequency jet ventilation - rates >60/min
- Combined frequency jet ventilation - rates > 60/min combined with normal rates

Jet ventilators

- No longer manufactured
  - Infrasonic Adult Star™
  - Bear 150™
  - Bunnell Life Pulse™
  - Accutronics
    - Mistral™
    - Monsoon™
Bunnell Life Pulse™
- Currently used for neonates and pediatric patients (< 28 kg) in USA
- Applied in tandem with companion ventilator that provides:
  - PEEP
  - sigh breaths
  - spontaneous breathing source gas

Bunnell Life Pulse™
- Controls - companion ventilator
  - FIO2 - ideally, same blender as jet
  - Rate ≤ 5/min - ideally zero
  - PEEP - adjusts mean airway pressure (MAP)
  - Peak inspiratory pressure (PIP)

Bunnell Life Pulse™
- Controls - jet
  - FIO2 - low-flow blender, ideally same blender as companion
  - Peak inspiratory pressure - (8 - 50 cm H2O)
  - Rate - (240 - 660/min)
  - On time (inspiratory time) - (0.02 - .034 sec.)

Click to see Life Pulse panel (click individual sections)
http://www.bunl.com/product-tabs2.html#

Bunnell Life Pulse™
- Monitors
  - jet PIP displays distal pressure (companion PIP displays proximal pressure)
  - PEEP
  - delta P - (PIP - PEEP)
  - mean airway pressure
  - servo pressure - servo-controlled drive pressure that adjusts flow to maintain PIP

Accutronics Mistral™
- Short-term ventilation; e.g., operating room
- Controls
  - rate 12-150/min
  - inspiratory time% 20-60%
  - drive pressure 5 - 40 psi

Accutronics Monsoon™
- Short or long-term (includes humidification)
- Controls
  - rate 12-1600/min
  - inspiratory time% 20-60%
  - drive pressure 5 - 40 psi
  - humidification - up to 100% RH

Click to see Accutronics Monsoon™ ventilator
**Accutronics Monsoon™**

- **Additional features**
  - color touch screen
  - detachable control panel
  - options:
    - video camera
    - EtCO2
    - TcCO2
    - double jet

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**Airway devices**

- **Bunnell LifePort™ adapter - for Life Pulse™ ventilator**
  - attaches to ETT and pressure monitoring port
  - approximates distal airway pressure
  - use the same size as ETT or larger

Click to see Bunnell LifePort™ adapter (click LifePort)

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**Airway devices**

- **Triple-lumen jet endotracheal tube**
  - ports
    - distal pressure monitoring
    - companion ventilator
    - jet ventilator

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**Airway devices**

- **Percutaneous catheter**
  - ventilation via cricothyrotomy
  - difficult airway management strategy

Click to see percutaneous catheter
http://archotol.ama-assn.org/cgi/content/full/131/10/886/00A50057F3

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**Airway devices**

- **Endotracheal jet catheter**
  - translaryngeal ventilation
  - microlaryngeal surgical procedures

Click to see jet ventilation catheter & laryngoscope
http://www.anesthesiology.org/content/90/2/460/F1.large.jpg

Click to see intubation with Hunsaker Mon-jet™ tube (1.2)
http://www.youtube.com/watch?v=51Y9Oxr7Dw
Airway devices
- Univent™ tube - bronchial blocking tube intended for single lung ventilation

HFJV Patient Management

Airway Management
- Suctioning - needed more frequently during initial hours on jet ventilation.

Initiation
- Patient already on conventional or oscillatory ventilation
- Follow Bunnell startup procedure, including attachment of LifePort adapter

FYI - Click to bookmark Bunnell Life Pulse™ slides and videos

Ventilator Control Adjustment
- Companion controls
  - FIO2 - both ventilators
  - PIP or TV, as previously adjusted
  - Rate
    - weaned to zero, as tolerated
    - desaturation during weaning indicates need for greater MAP
  - PEEP - adjust to maintain MAP
  - Oxygenation maintained with:
    - FIO2
    - MAP

Click for simulated Bunnell Life Pulse™ controls
http://www.bunl.com/Interactive-Life-Pulse.html

Ventilator Control Adjustment
- Jet controls
  - On time
  - Rate
  - PIP - adjusts TV (delta P)
Jet Control Adjustment

- **On time**
  - defaults to 0.02 sec.
  - usually left on default setting
  - at lowest rate (240) I:E = 1:12

- **Rate (240-660)** - not the primary control for PaCO2
  - typical jet rate > 10 times CMV rate
  - for small infants, start at 420/min
  - lower rates for:
    - larger infants
    - PIE
    - meconium aspiration
    - gas trapping, reversal of which may decrease PaCO2

Jet Control Adjustment

- **PIP - control over PaCO2**
  - adjusts TV (delta P)
  - with HFV, VE = f x TV^2 => smaller TV changes have greater effect
  - start with PIP 1-2 cm less than CMV PIP
  - adjust for desired PaCO2
  - transcutaneous CO2 monitor is helpful in adjusting PIP

Ventilation Monitoring

- **Servo pressure**
  - fluctuates like PIP with patient activity and position
  - should change in direction of PIP setting

- **Servo pressure**
  - decreased by:
    - decreased compliance
    - increased resistance
    - obstructed ETT
  - increased by:
    - increased compliance
    - decreased resistance
    - leak in system
  - increased servo P is usually good; but, may indicate leak

- **Proximal-distal pressure difference**
  - jet PEEP display is measured distally
  - CMV PEEP display is measured proximally
  - significant difference between distal and proximal indicates intrinsic PEEP (PEEPi)
  - decrease rate to eliminate PEEPi
Discontinuation
- Condition that precipitated need for HFJV must be resolved before weaning
- Wean slowly
- Maintain MAP for oxygenation

Discontinuation
- Decrease PIP slowly (1-2 cm H2O)
- Decrease PEEP, which controls the MAP, to 8 or less as consistent with adequate oxygenation
- Decrease FIO2 to 30%
- Change to CPAP or nCPAP when PIP < 15 cm H2O and CMV rate at or near CPAP

Case Scenarios

Case One
- 26 wk 700 g BG
- Intubation and surfactant in DR
- Initial ventilator settings TV = 12 mL, rate = 60/min, FIO2 = 60%; PEEP = 6 cm H2O - couldn't wean FIO2
- More surfactant - no changes (RDS)
- Over 36 H, PIP increased from low 30s to 55 cm H2O - see CXR after CMV

Click to see CXR before CMV

Click to see CXR after 36 H on CMV

Case One
- Diagnosis - PIE
- Conventional ventilator: FIO2 = 60%; MAP = 22 cm H2O; PIP = 55 cm H2O
- Initial settings for jet ventilation:
  ◆ Companion: FIO2 = 60%; PEEP = 12 (for MAP = 22); rate = 5/min
  ◆ Jet: FIO2 = 60%; PIP = 50 cm H2O; rate = 420/min; On time = .020
- ABGs: PaO2 = 60 mm Hg; SaO2 = 93%; PaCO2 = 35 mm Hg; pH = 7.42
- Over 24 H, FIO2 decreased to 42% and PIP decreased to 40 cm H2O
- PIE resolving on radiograph

Case One
- ABGs: PaO2 = 60; SaO2 = 93%; PaCO2 = 35; pH = 7.42
- Ventilator adjustments:
  ◆ Companion rate to zero - SPO2 decreased, increased MAP to 23 cm H2O with SPO2 rebound
  ◆ decreased PIP to 47 cm H2O, PCO2 increased to 36 mm Hg
- Over 24 H, FIO2 decreased to 42% and PIP decreased to 40 cm H2O
- PIE resolving on radiograph
Case One

- At 48 H on jet: ABGs: PaO2 = 70; SaO2 = 95%; PaCO2 = 32; pH = 7.46
- FIO2 weaned to 30%
- PIP weaned to 10 cm H2O
- PEEP weaned to 8 cm H2O
- Patient stable on CPAP 8 cm H2O; FIO2 = 30%
- Extubated to nCPAP

Case Two

- 41 wk, 3500 g BB
- Delivered with meconium in amnion and in upper airways
- Intubated, suctioned through ETT
- Lavaged with surfactant
- Placed on nCPAP = 6; FIO2 = 35%; SpO2 = 89% then to NICU
- 6 H later, SpO2 decreased and RR increased to 80/min

Click to see a radiograph of MAS http://img.medscape.com/fullsize/migrated/437/101/fp1206.04.fig1.jpg

Case Two

- Placed on volume-control ventilator with FIO2 = 50%; TV = 22 mL; rate = 40/min; PEEP = 6 cm H2O; PIP = 48 cm H2O; MAP = 18 cm H2O
- ABGs: PaO2 = 45 mm Hg; SaO2 = 81%; PCO2 = 76 mm Hg; pH = 7.18
- Changed to jet ventilator
- Settings??

Case Two

- Initial settings for jet ventilation
  - companion FIO2 = 60%; PEEP = 8 cm H2O for MAP = 18 cm H2O; rate = 5/min
  - jet FIO2 = 60%; rate = 360/min; PIP = 46 cm H2O
- ABGs: PaO2 = 42 mm Hg; PaCO2 = 75 mm Hg; pH = 7.10

Case Two

- Ventilator adjustments
  - companion PEEP increased to 10 cm H2O for MAP = 20 cm H2O; rate decreased to zero
  - jet rate decreased to 240/min
- ABGs: PaO2 = 59 mm Hg; SaO2 = 91%; PaCO2 = 55 mm Hg; pH = 7.27
- CXR - less hyperinflation
- Note: increased PIP might decrease PaCO2; but decreased rate worked by decreasing I:E

Case Two

- Over two days, CXR improved and patient stable on FIO2 = 38%; PIP = 22 cm H2O; PEEP = 8 cm H2O
- PIP weaned to zero; FIO2 weaned to 30% with patient stable
- Patient extubated to nCPAP
Summary & Review

- HFV types
- HFJV definition and types
- HFJV rationale
- Mechanisms for gas transport
- HFJV indications
- HFJV complications

Summary & Review

- Jet ventilators
  - Bunnell LifePulse™
  - Accutronics
    - Mistral™ - short-term only
    - Monsoon™
  - Bunnell controls
    - rate
    - PIP
    - on time

Summary & Review

- Jet airway devices
  - Bunnell LifePort™
  - triple-lumen jet endotracheal tube
  - cricothyrotomy catheter
  - translaryngeal catheter

Summary & Review

- HFJV management
  - control adjustments
    - oxygenation - MAP, FIO2
    - PaCO2 - PIP (delta P)
    - rate - decreased for air-trapping
  - monitoring
    - servo P
    - distal - proximal pressure difference
  - discontinuation

References

- Woodruff, K. Personal communications pertaining to Bunnell Life Pulse 2010.

References

References


- Stewart DL, Dela Cruz TV, Duncan SD, Cook LN. Response to high frequency jet ventilation may predict the need for extracorporeal membrane oxygenation. Eur Respir J. 1996 Jun;9(6):1257-60.